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FIELD DEMONSTRATION OF BIODEGRADABLE HYDRAULIC FLUID IN MILITARY TACTICAL AND CONSTRUCTION EQUIPMENT

INTERIM REPORT
TFLRF No. 339

by

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Under Contract to

U.S. Army TARDEC
Petroleum and Water Business Area
Warren, MI

Contract No. DAAK70-92-C-0059

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July 1999

Disclaimers

DTIC Availability Notice

Disposition Instructions

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE	2. REPORT DATE July 1999	3. REPORT TYPE AND DATES COVERED Interim, November 1997 - January 1999

Field Demonstration of Biodegradable Hydraulic Fluid in Military Tactical and Construction Equipment	5. FUNDING NUMBERS DAAK70-92-C-0059 WD 60
6. AUTHOR(S) Wright, B.R., Alvarez, R.A., Phillips, G., and Dr. Rhee, In Sik	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI) Southwest Research Institute P.O. Drawer 28510 San Antonio, Texas 78228-0510	8. PERFORMING ORGANIZATION REPORT NUMBER TFLRF No. 339
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army TACOM U.S. Army TARDEC Petroleum and Water Business Area Warren, MI 48397-5000	10. SPONSORING/ MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The U.S. Army is currently using four different types of hydraulic fluids/oils. The MIL-H-6083 and MIL-H-46170 are used for Armor vehicles, while MIL-L-2104 (10W) is used for construction equipment or other applications and MIL-46001 is used for industrial hydraulic systems. As a part of the development of the biodegradable hydraulic fluid program, a field demonstration was conducted at Ft. Bliss, TX for one year using military tactical and construction equipment. The demonstration was successfully completed, and no abnormal behavior was observed. This report summarizes the results of field demonstration for bioderadable hydraulic fluids in tactical and construction equipment.

14. SUBJECT TERMS Hydraulic fluids	Biodegradable	15. NUMBER OF PAGES 25
		16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-12

EXECUTIVE SUMMARY

Problems and Objectives: The primary hydraulic fluids used by the U.S. Army today are MIL-H-6083, MIL-H-46170, and MIL-H-46001. The other fluid used in construction equipment is MIL-L-2104-10w. None of these fluids are biodegradable. This program took the first step in investigating biodegradable hydraulic fluid performance in military construction and tactical equipment by conducting a one-year field demonstration. These vehicles were serviced with MIL-L-2104-10w, which is commonly used in construction and tactical equipment.

Importance of Project: This program provides basic information on the use of biodegradable hydraulic fluids as a replacement for petroleum-based fluids in construction and tactical equipment.

Technical Approach: Laboratory and field testing is being conducted in order to verify that biodegradable hydraulic fluids manufactured from various (canola, soy, rapeseed and syntetic) base stocks not only perform satisfactorily in the equipment, but remain stable in the process.

Accomplishments: Chemical analysis was performed on the fluid samples prior to testing and quarterly throughout the 12-month field demonstration. Results of this field demonstration indicate that it may be possible to simply flush and fill the hydraulic systems and utilize the off-the-shelf biodegradabe hydraulic fluids currently available.

Military Impact: The use of biodegradable fluids is more commonly mandated today due to an executive order. This demonstration is expected to provide the U.S. Army with options that will allow biodegradable hydraulic fluid to be used in military tactical and construction equipment.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period November 1997 through January 1999 under Contract No. DAAK70-92-C-0059. The work was funded and administered by the U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan. Funding was provided by the A_2P_3 program administered by Mr. Tom Landy (AMSTA TR-E/MATR/267), and Mr. Luis Villahermosa (AMSTA-TR-D/210) served as the TARDEC contracting officer's representative. Dr. Heidi Schreuder-Gibson of NATIK and Ms. Carmela Baily of USDA provided a congressional plus-up funding on the development of biodegradable hydraulic fluid program.

The authors would like to acknowledge the assistance of the renewable industries who provided candidate biodegradable hydraulic fluids for this field demonstration.

Special thanks is given to D. L. Wright and W.C. Mills of TFLRF for their help in preparing and editing this report.

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I. BACKGROUND

Hydraulic systems are essential components of military equipment ranging from aircraft flight control systems to construction and tactical equipment. A common problem in most hydraulic systems is the potential for leakage and the possibility of hydraulic fluid spillage during storage and use. The generation of hazardous wastes from petroleum-based or synthetic fluids results in both short- and long-term liability in terms of cost, environmental damage, and mission performance. Currently, the Resource Conservation and Recovery Act (RCRA) and DoD Hazardous Minimization (HAZMIN) Policy mandate that all military installations reduce the volume and toxicity of hazardous waste generated by petroleum-based products wherever economically feasible and environmentally necessary. To achieve the environmental goals, a number of recycling, re-refining, incineration, and field-bioremetiation technologies were recently used in the field, but with limited success. For this reason, the Fuels and Lubricants Technology Team of the U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC) is currently developing Biodegradable Hydraulic Fluids (BHFs) to replace military industrial and mobility hydraulic fluids, which are less compatible with the environment.

In response to the demand of military BHFs, a market study was conducted in 1994 to determine whether renewable hydraulic fluids would be suitable in military applications. Most BHF products were formulated with vegetable oils (i.e., rapeseed, sunflower, corn, soybean, canola) and synthetic esters, such as the polyol ester. The vegetable oils are becoming more important than synthetic ester-based oils because of their availability and low cost. In addition, the vegetable oils have excellent lubrication qualities, are nontoxic and biodegradable. Their chemical structures are triglycerides in which a variety of saturated, monounsaturated or polyunsaturated fatty acids are esterified to a glycerol backbone. The physical properties of a vegetable oil depend on the nature of its fatty-acid composition. These oils tend to oxidize at temperatures above 90°C and are considered unstable compared with conventional petroleum-based fluids. Also, the low-temperature capability (-15°C) significantly affects the outdoor mobility applications in which hydraulic systems may sit for extended periods at sub-zero temperatures. However, it appears that there is only one viscosity grade (ISO 32) available at this time, possibly due to the limited manufacturing process.

Synthetic esters, mainly based on trimethylpropane, polyol ester and pentaerythritol, are regarded as the best among the biodegradable base fluids. The biodegradability of these oils is comparable to vegetable oils, and their lubrication properties are very similar to mineral oils. The advantages of these oils are excellent low-temperature fluidity and aging stability. Therefore, they provide wide operational temperatures (-54 to 150°C) and have long shelf and service lives. On the other hand, synthetic esters cost more than mineral oils. Their differences are summarized in Table 1.

Table 1. Comparison of Base Fluids

Biodegradability ASTM D 5864, %	10-40	40-80	30-80
Viscosity Index	90-100	100-250	120-220
Pour Points, °C	-54 to -15	-20 to 10	-60 to -20
Compatibility with Mineral Oils	-	Good	Good
Oxidation Stability	Good	Poor to Good	Poor to Good
Service Life	2 years	6 months to 1 year	3 years
Relative Cost	1	2 to 3	4-6

In this study, 26 renewable hydraulic fluids were evaluated against the requirements of MIL-H-46001 as most samples were designed as industrial hydraulic fluids. The results showed that most of the renewable hydraulic fluids tested were very close to meeting the requirements of the MIL-H-46001 specification and were promising as candidate biodegradable military hydraulic fluids. These results were published in a TARDEC Technical Report[1,2] entitled "Evaluation of Environmentally Acceptable Hydraulic Fluids." However, these renewable products must be reformulated for use in military applications as they were originally designed for limited commercial applications.

In the second phase of this study, the target requirements for military BHFs were developed based on specific military needs and what is believed to be achievable with the current BHF formulation technology.[2] Most target requirements were consolidated with the current military hydraulic fluid specifica-

tions (MIL-H-46001, MIL-H-6083, and MIL-H-46170).[3,4,5] These target requirements were designed for Types I and II, which cover all types of renewable hydraulic fluids, such as vegetable or synthetic biodegradable fluids. Type I was designed for vegetable-based hydraulic fluids, while the synthetic BHFs are listed as Type II fluids. These fluids were also divided into five categories based on the ISO viscosity grades. The preliminary target requirements for BHFs are listed in Appendix A. These target requirements cover a wide range of operational temperatures (-54 to 150°C), a high biodegradability, a wide viscosity range, excellent antiwear and load carrying capacity, good elastomer compatibility, good oxidation stability, good fire resistance, and excellent rust and corrosion protection. Most test methods specified in these requirements were the ASTM standard test methods that are normally used for evaluating the current military hydraulic fluids. An ASTM biodegradable test method was adopted to evaluate the biodegradability of BHFs.[6] This test method was designed to determine the degree of aerobic aquatic biodegradation of fully formulated lubricants or additives on exposure to an inoculum under laboratory conditions. A toxicity test is also required to assess the environmental properties.

Based on the preliminary target requirements, 11 proposed BHFs were formulated by several lubricant companies and tested according to the testing protocol. All interim products met most requirements and provided very high flash and fire points comparable to those of military fire-resistant-type hydraulic fluids. The rapeseed-based fluid provided the highest biodegradability among all the fluids. Some of fluids with a high viscosity had difficulty in meeting the target requirement of biodegradability due to their high molecular weight and the types of materials.

To validate BHF products in the military applications, a field demonstration was initiated at Fort Bliss, TX using ten pieces of military construction equipment. The field demonstration has been completed, and this report presents the results of this study, finding, several recommendations, and a future plan.

II. FIELD DEMONSTRATION

As a result of the successful completion of the earlier phases of this program, a field demonstration was initiated to validate experimental BHF products in actual field equipment. The test site chosen for this

demonstration was McGregor Range, NM (field range location) and Fort Bliss, TX in El Paso (field range headquarters). In May 1997, members of TARDEC and TFLRF (TARDEC Fuels and Lubricants Research Facility at Southwest Research Institute [SwRI] in San Antonio, TX) staff visited the test site to coordinate the commencement of a pilot field demonstration with the Intermediate Maintenance Division of the 1st Combined Arms Battalion (CAS). For the field tests, five candidate BHF products were selected based on the previous laboratory evaluation. These field test samples consisted of one rapeseed-based, one soybean-based, one synthetic ester, and two canola-based BHF products. Their types, basestocks and physical properties are listed in Table 2.

Table 2. Biodegradable Hydraulic Fluids - Physical Property Data

Product Code	Type	Base stock	Viscosity 40ºC	Viscosity -15ºC	Pour Point ºC	Flash Point ºC	Acid No.	Four ball wear, mm	Biodegradability, %
A	I	Canola	35.8	575.5	-30	284	0.79	0.4	80
B	I	Rapeseed	39.2	649.8	-30	316	1.32	0.6	67
C	I	Soybean	48.3	953.9	-26	266	2.17	0.3	60
D	I	Canola	41.3	ND	-39	216	2.35	0.3	62
E	IIB	Dibasic ester + vegetable oil	33.6	ND	-60	242	0.82	0.3	NA*

* Not Available

The construction equipment used in this field demonstration consisted of three dump trucks, three grader roads, two loader scoops, a backhoe, and a wrecker. This equipment originally used 10-weight oil as their hydraulic fluids. The test vehicles were selected based on their availability and military application. The test fluids were selected for each piece of equipment based on its viscosity requirement of original hydraulic oils. Table 3 summarizes the construction equipment used in this demonstration and BHFs tested for each piece of equipment.

1. Green Oil Co. – Canola (A), HF-32/46E - Black Tag (code A)
2. Mobil Oil Co. - Rapeseed, 224H - Green Tag (code B)
3. Northland Oil Co. - Soybean - Yellow Tag (code C)
4. International Lubricants – Canola (B) - White Tag (code D)
5. International Lubricants - Synthetic - Blue Tag (code E)

Table 3. Demonstration Vehicles			
Nomenclature and Model No.	**Serial No.**	**Color Code**	**Hydraulic Oil**
Dump Trk. Int.	1756DCAL2392	Yellow Tag	Soybean, Northland
Dump Trk. Int.	1751DCA12381	Black Tag	Canola (A), 32/46E
Grader Road, 130G	7GB01224	Yellow Tag	Soybean, Northland
Loader Scoop, MW24C	Y9157388	Black Tag	Canola (A), 32/46E
Loader Scoop, JD410	342570	Green Tag	Rapeseed, 224H
Grader Road, 130G	7GB01221	Green Tag	Rapeseed, 224H
Dump Trk. GMC	7DIF4FV52111	White Tag	Canola (B), Type 1
Grader Road, 130G	7GB00867	Blue Tag	Syn., Type II
Loader Scoop, 680CK-B	9105460	Blue Tag	Syn., Type II
Trk. Wrecker, M816	C127-10713	White Tag	Canola (B), Type I

The changeover procedure consisted of the following steps:

1. Operate the vehicle for 15-20 minutes in order to warm the system.
2. Drain the fluid from the reservoir and total system such as pumps, lines and hoses.
3. Refill the system with the appropriate fluid (as shown in Table 3) and again operate the system for 15-20 minutes.
4. At the end of the second warm-up period, drain and replace fluid with a fresh charge of new (appropriate) fluid. The vehicle was ready to begin the one-year field demonstration.

Table 3 also shows tag colors. These color codes were placed on the vehicle to allow the operator to identify the fluid in the vehicle in order to prevent fluid-replacement errors.

After the completion of the changeover procedure, the vehicles were again operated for a short demonstration period in order to assure that the hydraulic system was operating normally.

Vehicular utilization is summarized in Table 4. Some of the utilization is reported in hours of operation

Table 4. Biodegradable Hydraulic Fluid Pilot Field Demonstration Program at McGregor Range Base Camp

Vehicle	Serial No.	Location	Miles/Hours at Changeover	Date of Changeover	Sampled Jan. 26-30 Miles/Hours on Test	Sampled April 27-30 Miles/Hours Since last sampling	Sampled August 3-7 Miles/Hours Since last sampling	E.O.T. Sample Sept. 28-Oct. 6 Total Test Miles/Hours	Hydraulic Oil Used/Oil Color Code
Dump Trk. Int.	1756DCAL2392	SR	46733	10/30/97	203.1	969.9	166	1339	Soybean, Nthland/Yellow
Dump Trk. Int.	1751DCA12381	SR	66109	10/29/97	125.9	575.4	216	917.3	Canola (A), 32/46E/Black
Dump Trk. GMC	7DIF4FV53111	SR	42525	11/17/97	154.3	1537.5	151.2	1843	Canola (B), Type I/White
Grader Road, 130G	7GB01224	MP	1055 hrs	10/30/97	124 hrs	25 hrs	40 hrs	209	Soybean, Nthland/Yellow
Grader Road, 130G	7GB00867	DA	2919.1 hrs	11/18/97	**	100 hrs	40 hrs	160	Synthetic, Type II/Blue
Grader Road, 130G	7GB01221	MP	113 hrs	10/27/97	61.9 hrs	30.7 hrs	19 hrs	136.3	Rapeseed, 24H/Green
Loader Scoop, 680CK-B	9105460	DA	3796.9 hrs	11/18/97	69.4 hrs	100 hrs	300 hrs	469.4	Synthetic, Type II/Blue
Backhoe, JD410	342570	DA	444 hrs	10/28/97	28 hrs	23.3 hrs	56 hrs	135.3	Rapeseed, 224H/Green
Loader Scoop, MW24C	Y9157388	MR	1232 hrs	10/29/97	27.5 hrs	97.7 hrs	43.4 hrs	196	Canola (A), 32/46E/Black
Trk. Wrecker, M816	C127-10713	MP	40070	11/19/97	207.1	1164.9	321.2	2054.9	Canola (B), Type I/White

SR = Shorad Test Site
DA = Donna Anna 16 Bay
MR = Meyer Range
MP = Motor Pool

and other data is reported in miles.

The results in the table above are reported according to the method of record on the vehicle. The utilization that was recorded was the normal utilization and was not intentionally modified for purposes of the test.

Figures 1-7 are photographs of typical vehicles used in the field demonstration. These vehicles were used and maintained by personnel from the Intermediate Maintenance Division at Fort Bliss, Texas. Inspections of the vehicles to be used in the demonstration were conducted at the beginning of the test and then quarterly until the final inspection as shown in Table 5. It should be noted that this table incorporates both the pre-test inspection results and the final condition prior to changeover to the original hydraulic fluid. The initial results are noted by an asterisk and changes in conditions are noted also. Criteria for seepage inspection results are also noted in Table 5.

As an overall assessment, some slight changes were noted in terms of leakage but no leaks were detected that caused the vehicle to be deadlined. According to the maintenance personnel at McGregor Range Maintenance Facility, the seepage rates that were observed were considered normal for this type of equipment.

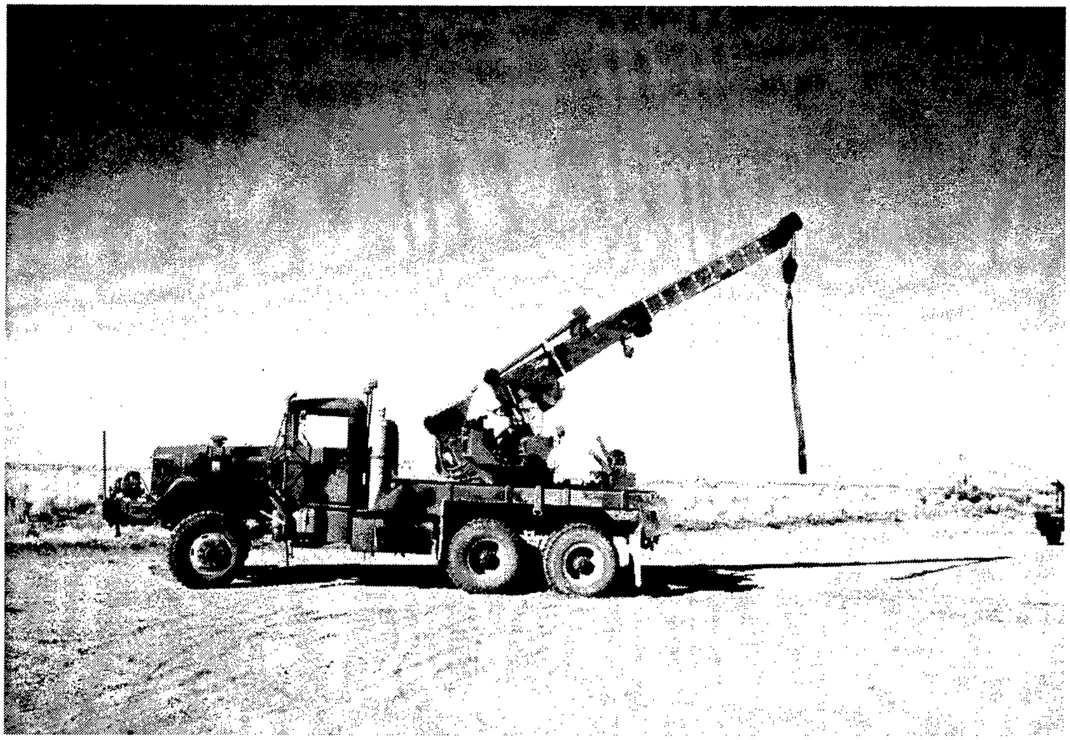
III. LABORATORY ANALYSIS

Laboratory analyses were conducted on the new and quarterly inspection samples. The results are reported later in the text. The protocol for testing was established based on prior laboratory experience with petroleum-based hydraulic fluids. A brief description of each test is described below.

<u>ASTM D-92 - Flash Point</u>: The standard method used to determine the flash point of petroleum products. Flash point measures the tendency of the fluid to form a flammable vapor mixture with air under controlled laboratory conditions. This data is used in shipping and safety regulations as defined by terms such as flammable and combustible fluids. Fluids, while in service, can undergo both physical and chemical changes, and changes in flash point can readily identify contaminants and other liquid dilutions.

<u>ASTM D-97 - Pour Point</u>: A standard test that is an index of the lowest temperature for use in certain applications. When conducting this procedure, the sample (after preliminary heating) is cooled at a specified rate and is examined at 3°C intervals for flow characteristics. The lowest temperature at which the fluid will flow is reported as the pour point.

Figure 1. Field Demonstration Vehicles



a. Truck Wrecker, M816

b. Road Grader, 130G

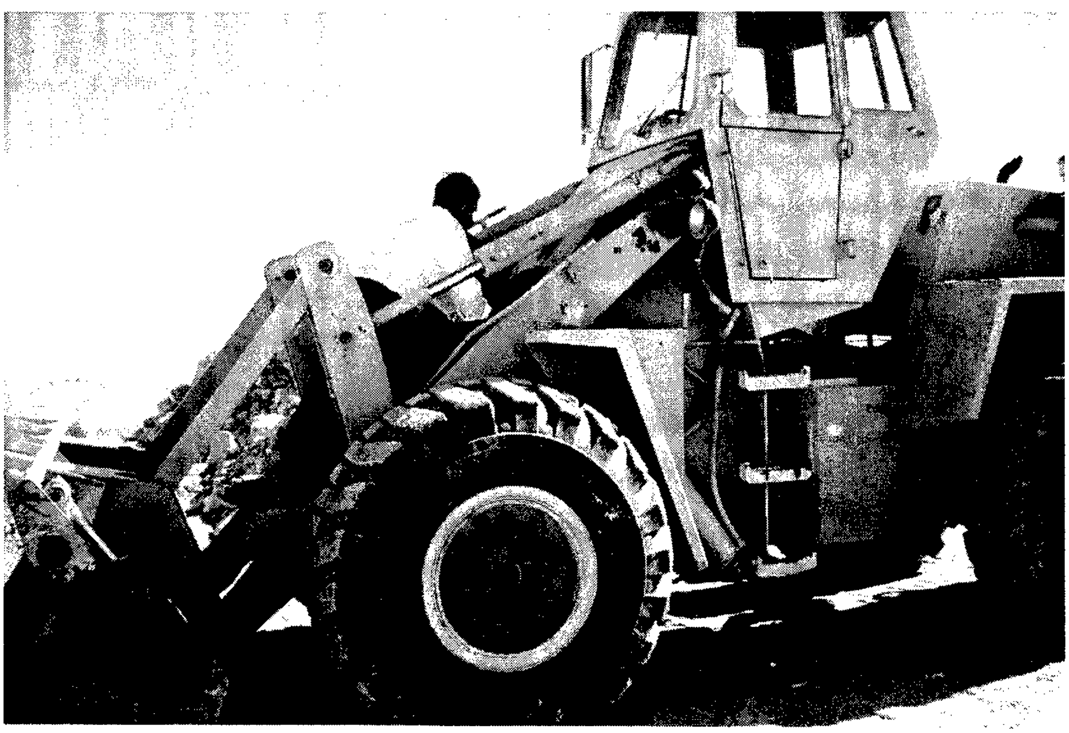
Figure 2. Field Demonstration Vehicles

a. Loader Scoop, MW24C

b. Loader Scoop, 680 CK-B

Figure 3. Field Demonstration Vehicles

a. Scoop Loader



b. Scoop Loader

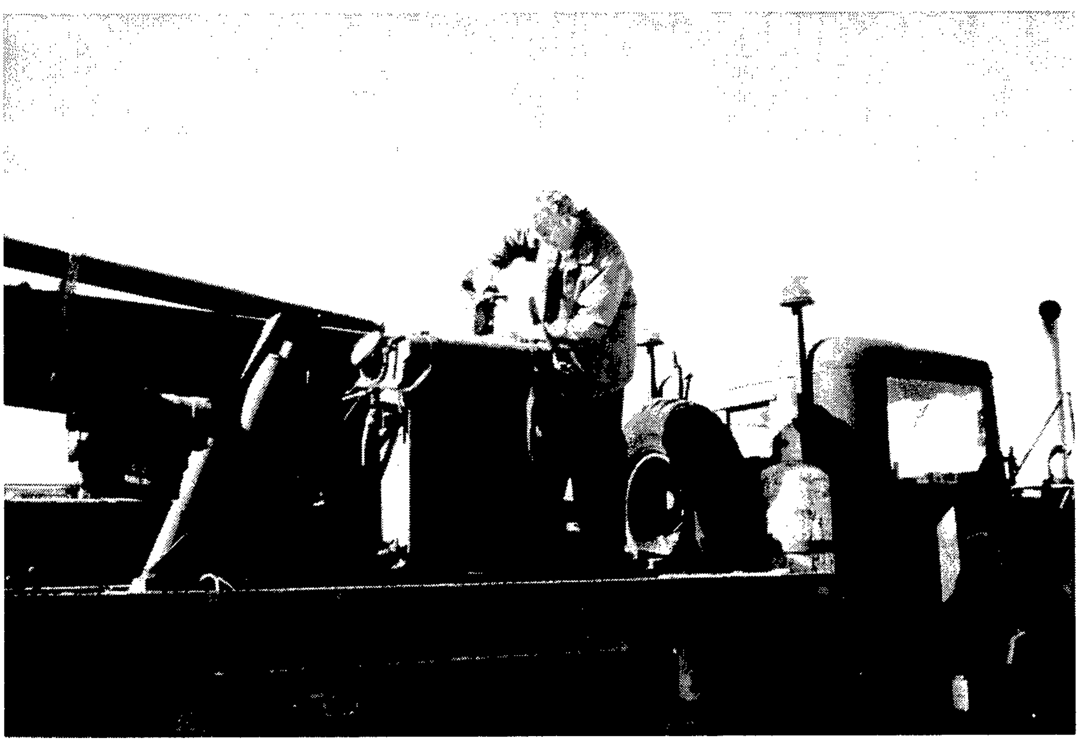
Figure 4. Field Demonstration Vehicles

a. Vehicle Servicing

b. Vehicle Servicing

Figure 5. Field Demonstration Vehicles

a. Lubricant Servicing



b. Field Sample Collection from Wrecker Truck

Figure 6. Field Demonstration Vehicles

a. Loader Backhoe FBEQ3

b. Dump Truck

Figure 7. Field Demonstration and Field Biodegradation Test Sites

a. Loader Backhoe, BHF Sample Collection System

b. Fluid Servicing

c. Field Biodegradation Test

Table 5. Vehicular Inspection Results

Condition of Hydraulic Components of Vehicles on the Biodegradable Hydraulic Fluid Pilot Field Demonstration Program at McGregor Range Base Camp.

1. Loader Scoop, 680CK-B, S/N: 9105460, Hydraulic Fluid: Synthetic Type II (Blue). Zero hours since last sampling, and 469.4 hours total to date on test.

   Cylinders Repaired and Status:

   *a. Main Boom-Elevation, Not leaking.
   *b. Main Boom Left, Slight.
   *c. Main Boom Right, Slight.
   *d. Front Bucket-Elevation, Not leaking.
   e. All other cylinders on the Loader Scoop were inspected and found to be not leaking.
   f. Eight hoses were replaced.
   g. Equipment has been deadlined for engine inoperability since last sampling.

2. Truck Wrecker, M816, S/N: C127-1073, Hydraulic Fluid: Canola(B) Type I (White). 361.7 miles since last sampling, and 2054.9 total miles to date on test.

   a. Elevation cylinders, left and right - Slight seepage**.
   b. Hose replaced on left elevation cylinder.

3. Grader Road, 130G, S/N: 7GB01224, Hydraulic Fluid: Soybean (Yellow). Approximately 20 hours since last sampling, and 209 hours total to date on test.

   *a. Rotating Table, left/right cylinder - Slight seepage.
   *b. Steering cylinder, right side - Moderate seepage.
   *c. Blade, left/right cylinder - Slight seepage.
   d. Table Tilt - Slight seepage.

Condition of Hydraulic Components of Vehicles on the Biodegradable Hydraulic Fluid Pilot Field Demonstration Program at McGregor Range Base Camp.

4. Grader Road, 130G, S/N: 7GB01221, Hydraulic Fluid: Rapeseed (Green). 25.7 hours since last sampling, and 136.3 hours total to date on test.

   *a. Blade tilt cylinder - Moderate.
   b. Blade - up/down - left side - Slight seepage.
   *c. Steering cylinder - left side - Moderate seepage.
   *d. Steering cylinder - right side - Slight seepage.

Table 5. Vehicular Inspection Results (continued)

5. Backhoe, JD410, S/N: 342570, Hydraulic Fluid: Rapeseed (Green). 28 hours since last sampling, and 135.3 hours total to date on test.
   - *a. Steering cylinder - Heavy seepage.
   - b. Front bucket tilt - right side - Moderate seepage.
   - c. Rear bucket articulation cylinder - Line/Fitting - Slight leak.

6. Loader Scoop, MW24C, S/N: Y9157388, Hydraulic Fluid: Canola(A) (Black). 27.4 hours since last sampling, and 196 hours total to date on test.
   - a. Bucket elevation cylinder, right - Moderate seepage.
   - *b. Bucket dump cylinder, left - Moderate seepage.
   - *c. Bucket dump cylinder, right - Slight seepage.
   - *d. Articulating/Steering cylinder, right side - Slight seepage.

7. Truck Dump, International, S/N: 1756DCAL2392, Hydraulic Fluid: Soybean (Yellow). Zero miles since last sampling, and 1339 miles total to date on test.
   - *a. Main bed dump cylinder - Slight seepage.

8. Truck Dump, International, S/N: 1751DCA12381, Hydraulic Fluid: Canola(A) (Black). Zero miles since last sampling, and 917.3 miles total to date on test.
   - a. No apparent leaks anywhere on the vehicle.

9. Truck Dump, GMC, S/N: 7DIF4FV52111, Hydraulic Fluid: Canola(B), Type I (White). Zero miles since last sampling, and 1843.2 miles total to date on test.
   - a. No apparent leaks anywhere on the vehicle.

10. Grader Road, 130G, S/N: 7G00867, Hydraulic Fluid: Synthetic Type II (Blue). Approximately 20 hours since last sampling, and 160 hours total to date on test.
    - a. Blade, left-right - Heavy seepage.

* Condition existed prior to hydraulic fluid changeover.

** Seepage is described as enough fluid over a short period of time (one to two weeks) to collect a layer of dirt/dust over the wetted area. The various degrees of seepage are described as follows:

- a. Slight = the covering layer of dirt/dust not visibly wet.
- b. Moderate = The covering layer of dirt/dust visibly damp.
- c. Heavy = The covering layer of dirt/dust visibly wet.

ASTM D-445 - Kinematic Viscosity: Determined by measuring the time it takes for a volume of liquid to flow under gravity through a tube that is a calibrated glass capillary. The flow properties of hydraulic fluids are very important since the correct operation of the equipment depends upon the appropriate viscosity of the liquid at certain temperatures.

ASTM D-664 - Acid Number: A measure of the relative changes that occur in oil during use under oxidizing conditions. The test method is a titrating procedure that is controlled by color indicator and is expressed as milligrams of potassium hydroxide per gram of sample required to titrate to a specified end point. The end point is determined by the change in color of the dye indicator. The acid number can be used as a guide in quality control as an in-service measure of degradation.

ASTM D-1744 - Water Content - by Karl Fischer Reagent is a test method to determine water concentrations from 50 to 1000 mg/kg in liquid petroleum products. The water concentration in petroleum products can be very important in terms of product quality and performance. For instance, water in fluids can greatly affect the low temperature performance of fuels and fluids. Water can also indicate a potential leak in the system, can solubilize and precipitate additives and can affect lubricity. It is believed that certain of the biodegradable fluids have a greater affinity for water than a similar application petroleum fluid and can, therefore, be more critical in areas of high humidity.

Discussion of Laboratory Analysis -Table 6 presents the results of the laboratory analyses conducted on the new and used lubricant samples. These results will be discussed by fluid type rather than vehicle type.

Soybean - Soybean fluid was used to service Dump Trk. 2392. Table 6-A lists the results. There were no problems with the fluid that would indicate a chemical breakdown from the fluid chemistry or a hardware malfunction. Table 5, item 7 indicates no change in the hydraulic system during the field demonstration.

Table 6. Hydraulic Fluid Chemical Analysis

6-A

Dump Trk. 2392	Soybean				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25151	25345	25464	25590	25661
Pour Point (°C)	-26	-25	-27	-30	-34
Vis (40°C)	45.30	45.90	45.43	45.34	45.43
Vis (100°C)	9.47	9.77	9.64	9.71	9.69
Vis (-40°C)	*	*	*	*	*
Acid No.	1.42	1.24	1.90	1.59	1.20
Flash Pt. (°C)	244	246	241	249	250
Water Content	0.100	0.044	0.049	0.080	0.145
*Appeared as a semi-solid at this temperature					

6-B

Dump Trk. 2381	Canola (A)				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25154	25345	25456	25592	25652
Pour Point (°C)	-35	-28	-29	-28	-32
Vis (40°C)	28.50	28.20	28.05	25.36	30.41
Vis (100°C)	7.04	6.96	6.90	6.99	6.69
Vis (-40°C)	*	*	*	*	*
Acid No.	0.39	0.32	0.40	0.32	0.59
Flash Pt. (°C)	237	224	225	229	240
Water Content	0.057	0.041	0.049	0.064	0.180
*Appeared as a semi-solid at this temperature					

6-C

Dump Trk. GMC	Canola (B)				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25225	25346	25460	25588	25660
Pour Point (°C)	-34	-39	-32	-37	-40
Vis (40°C)	31.90	31.80	31.89	32.35	32.35
Vis (100°C)	7.12	7.17	7.14	7.30	7.28
Vis (-40°C)	*	*	*	*	*
Acid No.	0.74	0.82	1.08	0.65	0.76
Flash Pt. (°C)	226	229	233	270	237
Water Content	0.087	0.070	0.106	0.111	0.180
*Appeared as a semi-solid at this temperature					

Table 6. Hydraulic Fluid Chemical Analysis (continued)

6-D

Grader 1224	Soybean				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25153	25349	25458	25580	25658
Pour Point (°C)	-25	-30	-27	-32	-37
Vis (40°C)	44.20	35.50	34.35	34.63	34.01
Vis (100°C)	9.62	7.67	7.40	7.50	7.38
Vis (-40°C)	*	*	*	*	*
Acid No.	1.16	1.23	2.04	1.17	1.80
Flash Pt. (°C)	238	213	205	214	219
Water Content	0.093	0.056	0.070	0.090	0.138
*Appeared as a semi-solid at this temperature					

6-E

Grader 1221	Rapeseed				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25156	25348	25455	25584	25659
Pour Point (°C)	-29	-25	-32	-37	-32
Vis (40°C)	37.00	35.20	34.86	34.93	34.87
Vis (100°C)	8.21	7.82	7.75	7.79	7.76
Vis (-40°C)	*	*	*	*	*
Acid No.	0.54	0.51	0.46	0.38	0.39
Flash Pt. (°C)	252	252	241	264	243
Water Content	0.039	0.040	0.050	0.069	0.100
*Appeared as a semi-solid at this temperature					

6-F

Grader 0867	Synthetic				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25214	No data	25462	25582	25653
Pour Point (°C)	-53	No data	-50	-49	<-57
Vis (40°C)	29.70	No data	24.56	28.18	25.83
Vis (100°C)	7.7	No data	5.75	5.92	5.85
Vis (-40°C)	**	No data	**	**	**
Acid No.	0.72	No data	0.87	0.87	0.71
Flash Pt. (°C)	229	No data	219	222	225
Water Content	0.073	No data	0.115	0.125	0.353
** TVTM - Too viscous to measure					

Table 6. Hydraulic Fluid Chemical Analysis (continued)

6-G

680 CK-B	Synthetic				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25228	25351	25457	25590	25655
Pour Point (°C)	-56	-56	-56	-53	<-57
Vis (40°C)	30.80	25.90	25.82	25.98	26.18
Vis (100°C)	7.24	6.06	6.32	6.31	6.36
Vis (-40°C)	**	**	**	**	**
Acid No.	0.90	0.93	0.74	0.67	0.60
Flash Pt. (°C)	222	221	225	230	227
Water Content	0.092	0.142	0.120	0.131	0.420
** TVTM - Too viscous to measure					

6-H

JD-410	Rapeseed				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25155	25350	25463	25594	25654
Pour Point (°C)	-31	-34	-33	-33	-38
Vis (40°C)	35.90	35.20	35.39	35.48	35.61
Vis (100°C)	7.62	7.23	7.31	7.28	7.48
Vis (-40°C)	*	*	*	*	*
Acid No.	0.60	0.81	0.92	0.62	0.55
Flash Pt. (°C)	248	252	235	237	252
Water Content	0.072	0.053	0.060	0.086	0.128
* Appeared as a semi-solid at this temperature					

6-I

MW-24C	Canola (A)				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25149	25343	25461	25586	25657
Pour Point (°C)	-33	-35	-29	-28	-30
Vis (40°C)	28.30	27.90	27.81	28.31	28.40
Vis (100°C)	6.89	6.76	6.68	6.64	6.63
Vis (-40°C)	*	*	*	*	*
Acid No.	0.29	0.21	0.19	0.33	0.34
Flash Pt. (°C)	214	220	213	237	223
Water Content	0.052	0.075	0.050	0.084	0.110
*Appeared as a semi-solid at this temperature					

Table 6. Hydraulic Fluid Chemical Analysis (continued)

6-J

M816 Wrecker	Canola (B)				
Date of Sample	Initial	Q1	Q2	Q3	Q4
AL#	25231	25347	25459	25576	25656
Pour Point (°C)	-35	-35	-30	-32	-38
Vis (40°C)	31.70	31.60	31.71	31.68	32.10
Vis (100°C)	7.46	7.39	7.42	7.45	7.39
Vis (-40°C)	*	*	*	*	*
Acid No.	0.62	0.78	0.82	0.66	0.66
Flash Pt. (°C)	227	229	233	236	240
Water Content	0.091	0.053	0.062	0.144	0.181
*Appeared as a semi-solid at this temperature					

The second vehicle to be serviced with soybean fluid was Grader 1224 and is listed in Table 6-D. There are several minor changes that appear consistent and occur during the first quarter. The pour point decreases during the test period, and the viscosity shows a decreasing trend. Also during the service period, the flash point decreased, but remained more constant in Table 6-A over the same time period. The condition of the hardware, as shown in Table 5, item 3, indicates only a slight seepage during the test period, and the performance was reported as normal.

Canola – The two Canola oils have been evaluated in this demonstration. These oils were originally supplied by two different renewable oil companies, and their physical properties are similar. Canola (A) oil was used to service Dump Trk. 2381, Table 6-B. When reviewing the chemical analysis, there do not appear to be changes that should be noted. Table 5, item 8 indicates that no problems or leaks occurred during the test period.

Canola (A) oil was also used to service Loader Scoop, MW24C. A review of the chemical analysis, Table 6-I, indicates that there are no changes to indicate a problem within the system. Also in Table 5, item 6, although there were several minor deficiencies noted at the initial inspection, no further changes were noted during the service period.

Canola (B) oil was used to service Dump Trk. GMC shown in Table 6-C. The results of the chemical analysis indicate essentially, no changes during the field demonstration period and no operating/performance deficiencies were noted. Table 5, item 9 also indicated no changes in system condition over the field demonstration period.

Canola (B) was also used to service Trk. Wrecker, M816 shown in Table 6-J. Reviewing the results of the chemical analysis shown in the table, no or only minor changes are noted and also correlate with the results from Table 6-C. Table 5 indicates that a slight seepage developed during the test period but was not severe enough to deadline the vehicle. This leak was detected during the first quarter of operation. Also at that time, an elevation cylinder hose was replaced.

Synthetic – The term synthetic is used to refer to the blend of dibasic ester and vegetable oil. Synthetic-based fluid was used to service Grader 0867, Table 6-F. This synthetic fluid had a lower pour point, lower viscosity and lower flash point than the other test fluids. The post-test analysis indicated a stable fluid with normal in-use changes. One interesting result was the water content, which was the highest of the test fluids. Another interesting result during the fourth quarter was the increase in water content on almost all of the samples. It is possible that the weather was cooler and that a higher humidity caused this increase. It should be noted that heavy seepage occurred during the test period and started during the second use period. It should also be noted that the -40°C viscosity is probably affected by the contamination of the MIL-H-2104-10w residue after changeover.

The second vehicle, Scoop Loader, 680CK-B, was also serviced with synthetic fluid as shown in Table 6-G. There did not appear to be any major changes during the use period, however, as noted above, the water content rose considerably higher than the new fluid. However, the importance of this increase in moisture is unknown in terms of stability and performance. As shown in Table 5, item 1, this vehicle had some slight seepage problems but was deadlined for engine failure during a portion of the test period.

Rapeseed – Rapeseed-based fluids were used to service Road Grader 1221 as shown in Table 6-E. Reviewing the results of the various chemical tests indicate no significant changes that would cause a mechanical failure. The condition of the hydraulic system as shown in Table 5, item 4 shows only a

slight seepage in the blade-elevation system, which occurred during the 12-month field demonstration. The leaks that were noted prior to the initiation of the test did not appear to change during the demonstration period. The second vehicle serviced with the rapeseed-based fluid was the John Deer Backhoe JD410 shown in Table 6-H. Results of the chemical analysis indicate very little change in the fluid properties that were measured. These results were similar to those observed in the Road Grader 1221 (above). Table 5, item 5 shows that two leaks developed, one in the front bucket and one in the rear bucket. As mentioned before, the leaks did not cause the vehicle to be deadlined.

Figures 8 and 9 are plots of typical changes that were determined for a vegetable and synthetic base fluid. Only slight variations occurred in viscosity and acid number. These results indicate the stability of this type of fluid even when tested in a desert environment.

IV. FIELD BIODEGRADATION TEST

As part of this field demonstration, a field biodegradation test was set up at Fort Hood, TX. All five candidate BHF products are being tested using Fort Hood's bioremediation procedure. Also, the conventional non-biodegradable military hydraulic fluid, MIL-H-46170 is being tested as a reference fluid. For the field performance test, BHFs were mixed with soil and fertilizer, and microbes were applied. The contaminated soil is then plowed and tilled in order to increase homogeneity. The fertilizer and microbes are distributed, and oxygen transfer is increased by promoting atmospheric diffusion. Water is applied to the soil as necessary. The soil samples are collected and analyzed to ensure cleanup levels have been reached before soil is reused. The analytical method used in this evaluation is the TNRCC method 1005 for Total Petroleum Hydrocarbon. No data are available at this point because the tests were initiated only one month ago. The results will be compared with the laboratory data. Figure 7c shows the field biodegradability test site established at Fort Hood, TX.

V. CONCLUSIONS

The successful completion of this field demonstration provides strong justification for continued investigation of biodegradable-based fluids as a permanent replacement for less-biodegradable, petroleum-

based fluids. Worldwide concern over fluid spills and disposal problems must continue to be addressed. Even though this field demonstration was initiated by only a flush and fill of the test vehicles with fluids from different manufacturers, satisfactory performance was provided by the various fluids. During the demonstration periods, there was no biodegradation in storage/or active use. For these reasons, BHF can be used in the military tactical and construction equipment. In recent years, the interest in environmentally friendly fluids has increased for suitable applications, especially where sensitive ecosystems are involved. Specific applications must be assessed in terms of realistic concepts, in addition to being technically feasible and cost effective. It is probable that, as biodegradability becomes more widely required, increased demand should result in wider availability and lower costs.

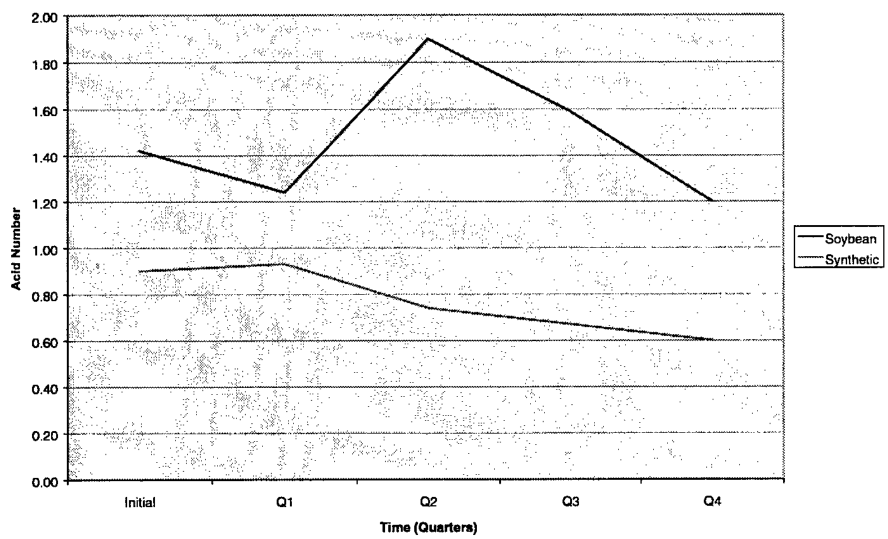


Figure 8. Typical Acid Number vs. Time

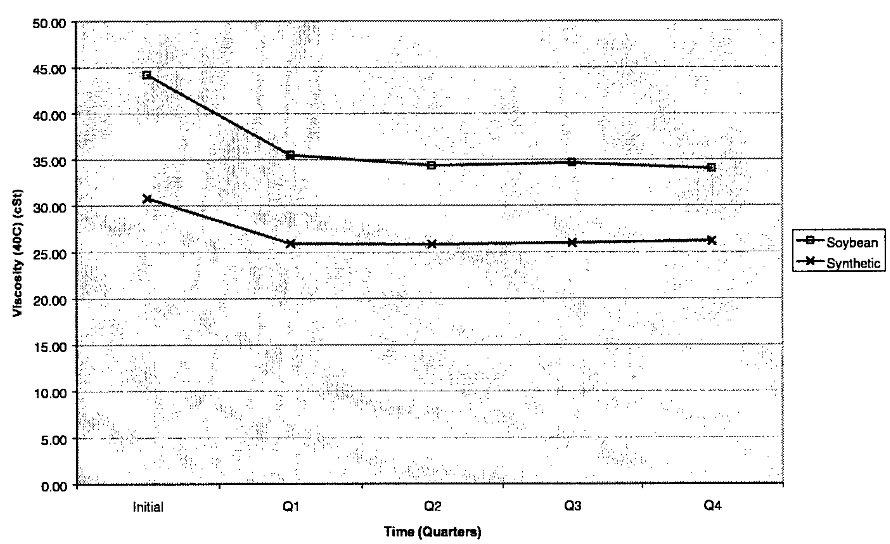


Figure 9. Typical Changes in Viscosity vs. Time

VI. RECOMMENDATIONS

The following recommendations are provided:

1. More selective testing should be continued in order to select the best candidate for general use or for the development of a universal biodegradable basestock.
2. Along with testing, the use of compatible elastomeric materials in new equipment for major overhauls should be encouraged when feasible.
3. While this field demonstration was considered successful, other environmental factors, such as colder climates, should be incorporated into the field test matrix. The Ft. Bliss, TX field test should be considered as a desert test facility, i.e., hot and dusty.
4. The application of biodegradable base fluids in other tactical and combat vehicles should be considered. Due to the low-temperature constraints, reformulation may be necessary, as well as the seal swell requirements.

VII. FUTURE PLAN

If funding is available, a field demonstration should be extended to the other military hydraulic systems, such as tactical and combat vehicles.

VIII. REFERENCES

1. In-Sik Rhee, "Evaluation of Environmentally Acceptable Hydraulic Fluids", TARDEC, Fort Belvoir, VA, 1995.
2. In-Sik Rhee, "Development of Biodegradable Hydraulic Fluids for Military Applications", U.S. Army TARDEC, Warren, MI, 1997.
3. Military Specification MIL-H-46001, Hydraulic Fluids, Petroleum Based, for Machine Tools, 7 December 1989.
4. Military Specification MIL-H-6083, Hydraulic Fluid, Petroleum Base, for Preservation and Operation, 8 February 1990.
5. Military Specification MIL-H-46170, Hydraulic Fluid, Rust Inhibited, Fire Resistant, 17 November 1993.
6. Goyan, R.L., et al. "Biodegradable Lubricants", Lubrication Engineers, September 1997.

APPENDIX A
TARGET REQUIREMENTS FOR MILITARY BIODEGRADABLE HYDRAULIC FLUIDS

Table A-1. Target Requirements for Military Biodegradable Hydraulic Fluids

Test	Method	Type I	Type II				
			A	B	C	D	E
ISO Grade	ASTM D 2422	NR	15	32	46	68	100
Viscosity, 40°C min, cSt	ASTM D 445	34.2 - 41.8	13.5 - 16.5	28.8 - 35.2	41.4 - 50.6	61.2 - 74.8	90.0 - 110
Viscosity Index, min	ASTM D 2270	184	140	140	140	140	140
Viscosity, -15°C, max, cSt	ASTM D 445	2300	200	1,000	1,300	1,500	NR
Pour point, °C, max	ASTM D 97	-25	-54	-40	-26	-26	-12
Flash point, °C, min	ASTM D 92	250	180	240	240	250	250
Fire point, °C, min	ASTM D 92	320	190	260	260	260	260
Acid or base number, mgKOH/g, max	ASTM D 664	1	1	1	1	1	1
Water content, %, max	ASTM D 1744	0.05	0.05	0.05	0.05	0.05	0.05
Rust Prevention	ASTM D 665B	pass	pass	pass	pass	pass	pass
Copper Corrosion, max	ASTM D 130	1b	1b	1b	1b	1b	1b
Galvanic corrosion	FTM 5322	pass	pass	pass	pass	pass	pass
Low-temperature stability, -15°C, 72 hrs	FTM 3458	pass	pass (-54°C)	pass	pass	pass	pass
Oxidation stability (PDSC), minutes, min	ASTM D 6186	20 (155°C)	20 (180°C)	20 (180°C)	20 (180°C)	20 (180°C)	20 (180°C)
Thermal stability, mg/100 ml, max	ASTM D 2070	25	25	25	25	25	25
Swelling of synthetic rubber, NBR-L, %, max	FTM 3603	35	35	35	35	35	35
Evaporation loss, %, 100°C, 1 hr, max	ASTM E 1131	2	2	2	2	2	2
Four ball wear, mm, max	ASTM D 4172	0.65	0.65	0.65	0.65	0.65	0.65
Biodegradability, %, min	ASTM D 5864	60	60	60	60	60	60
Toxicity, min	ASTM D 6046	1,000	1,000	1,000	1,000	1,000	1,000
Foaming	ASTM D 892	65/10	65/10	65/10	65/10	65/10	65/10
Workmanship	Army method	pass	pass	pass	pass	pass	pass
Particle Size[1]	particle counter	pass	pass	pass	pass	pass	pass
Storage stability[2], 100°C, 1 month	Army method	pass	pass	pass	pass	pass	pass

1. Particle Size Ranges — Allowable number (max)

Particle Size Ranges	Allowable number (max)
5-25	10,000
26-50	250
51-100	50
over 100	10

2. Storage Stability

Viscosity change	10%
PDSC, induction time change	10%
Acid number change, mg, max	2 mg

Lubricants Distribution List

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ODUSD ATTN: (L) MRM PETROLEUM STAFF ANALYST PENTAGON WASHINGTON DC 20301-8000	 1	CDR DEFENSE SUPPLY CTR RICHMOND ATTN: DSCR VB DSCR VC DSCR JBTB 8000 JEFFERSON DAVIS HWY RICHMOND VA 23297-5678	 1 1 1
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QUANTICO VA 22134-5010

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WL/POSL 1
1790 LOOP RD N
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AIR FORCE WRIGHT LAB 1
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WRIGHT PATTERSON AFB
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KELLY AFB TX 78241-5603

SA ALC/LDPG
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